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FRACTAL ANALYSIS OF TIDE GAUGE DATA

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One of the important consequences of Global warming is the general rise in mean sea level. There have been several recent reviews of sea level rise and the consequence of climate change. Long term changes of mean sea level are called secular changes. The global changes in the mean sea level are called the eustatic changes, whereas the vertical movements of the land are called eperiogenic movements. Out of these causes of sea level rise, only the eustatic rise is universal one. It also appears that tide gauge records contain long period fluctuations (5-100 years) which indicate that the accurate extrapolation of small sea level rise values from the data is very difficult. For nearly a century, relative mean sea level has maintained a steady rise at many tide gauge stations around the world. The relative mean sea level change at a particular location is the difference between eustatic change and any local change in land elevation [1,2].

Weather and climate system has low dimensional attractors. A consistent feature of weather and climate data is that they are aperiodic and their deviations from periodicity cannot be explained by conventional linear models of time series analysis.

It is therefore essential that the nature of the sea level change is analysed and modelled in order to assess the changes from one coastline to other or from the changes taking place in one ocean from the other neighbouring oceans. In this study the approach to analyse and visualize such a comparison is done through calculating the fractal dimension of the time series on annual averages of mean sea level variations for different stations in four countries representing two different oceans regionally.

The tide gauge data on the coastal stations of the whole world is maintained by the Permanent Service of Mean Sea Level (PSMSL) at their site. The annual data on the tide gauge data were obtained through ftp for analysis. Five coastal stations in India namely, Bombay, Cochin, Madras, Vishakhapatnam and Sagar were considered [4] to estimate the fractal dimension of the tide gauge data. Using the same technique for interpolating the data points between given observed points, namely, IFS technique, the fractal dimensions were calculated for other coastal stations in India for which longer time series were available. This was done as an additional exercise to check the variation between the values in the fractal dimensions for the coasts of India. For the construction of the fractal interpolation algorithm, consider a set of data $\{(x_i, z_i) ; i = 0,\dots,N\}$ and construct an IFS in $\Re^2$ such that its attractor, which is a graph of continuous function $f : [x_0,x_N] \rightarrow \Re$, interpolates the data. The IFS technique is described in detail elsewhere [3]. Consider the IFS of the form $\{\Re^2, \omega_n, n = 1, \dots, N\}$, where the maps are affine transformation

$$\omega_n \begin{pmatrix} x \\ z \end{pmatrix} = \begin{pmatrix} a_n 0 \\ c_n d_n \end{pmatrix} \begin{pmatrix} x \\ z \end{pmatrix} + \begin{pmatrix} e_n \\ f_n \end{pmatrix}$$

This is constrained by the data

$$\omega_n \begin{pmatrix} x_0 \\ z_0 \end{pmatrix} = \begin{pmatrix} x_{n-1} \\ z_{n-1} \end{pmatrix} \text{ and } \omega_n \begin{pmatrix} x_N \\ z_N \end{pmatrix} = \begin{pmatrix} x_n \\ z_n \end{pmatrix}$$

we get

$$a_n = (x_n - x_{n-1})/(x_N - x_0),$$
$$e_n = x_N x_{n-1} - x_0 x_n)/(x_N - x_0),$$
$$c_n = (z_n - z_{n-1})/(x_N - x_0) - d_n(z_N - z_0)/(x_N - x_0),$$
$$f_n = (x_N z_{n-1} - x_0 z_n)/(x_N - x_0) - d_n(x_N z_0 - x_0 z_N)/(x_N - x_0)$$

where d_n is any real number. If $\sum_{n=1}^{N} |d_n| > 1$, the fractal dimension is the unique real solution D of

$$\sum_{n=1}^{N} |d_n| a_n^{D-1} = 1.$$

It was found that the fractal dimensions when calculated for Kandla, Calcutta (Garden Reach), Diamond Harbour and Tribeni fall in the range of 1.2 and 1.3 as obtained earlier [4]. It can be said that the fractal dimensions obtained for sea level variation in the coasts of India fall in the range between 1.2 and 1.3.

The natural question now is whether such a behaviour is seen in other nearby oceans also, or if there is any difference in the behaviour of the Ocean which may be reflected on the value of the fractal dimension. In the immediate neighbourhood, the tide gauge data on Singapore coastal line were analysed. The three stations, Jurong, Sembawang and Sultan Shaol were considered for analysis and which showed similar range of fractal dimensions. The coast of Thailand where the three stations, Fort Ph. Chimkalao, Ko Lak and Ko Sichang show the fractal dimensions varying between 1.2 and 1.3, which is similar to the results obtained earlier.

To check and compare the fluctuations of sea level with respect to their fractal dimensions, from one ocean to other, the coastal stations of China representing Pacific Ocean were considered. The four stations in China namely Kanmen, Quihuan, Xiamen and Zhapo when analysed through IFS technique give exactly similar results as obtained earlier.

The fractal dimensions of sea level data for both Indian and Pacific Oceans are obtained and found to lie between 1.2 and 1.3. These non-integer values of the dimensions suggest small number of variables representing the system.

References

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